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Part II: The Aquatic Macroinvertebrates of Trout Creek, Colorado

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ENVIRONMENTAL EFFECTS OF WESTERN COAL SURFACE MINING PART II - THE AQUATIC MACROINVERTEBRATES OF TROUT CREEK, COLORADO

by

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FOREWORD

This study describes the impact of surface coal mining in Colorado on aquatic invertebrates. It is one in a series of reports delineating the aquatic effects of western energy development. Effects of this mining activity were minimal during part of the year and the presence of a buffer strip seems to be a desirable control feature to reduce impacts.

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ABSTRACT

A study was conducted on Trout Creek in northwestern Colorado to assess effects of coal mine drainage on stream macroinvertebrates. Density and biomass exhibited a general increase in the downstream direction throughout the study area and showed marked seasonal variation. Aquatic insects comprised over 90% of the fauna with caddisflies (Trichoptera) predominating. Diversity did not vary significantly throughout the study area. None of the parameters measured showed any definite indication of stressed conditions in the macroinvertebrate community during the study period. Water quality was diminished primarily during spring runoff and the invertebrates seemed able to withstand this short period of water quality degradation. The buffer zone present between the mine area and Trout Creek may decrease the effects of mine drainage and should remain to insure the maintenance of a stable macroinvertebrate community in Trout Creek.

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ACKNOWLEDGMENTS

The Natural Resource Ecology Laboratory, Colorado State University, provided support facilities and coordinated research activities. The authors wish to thank Mr. R. G. Dufford, Department of Botany and Plant Pathology, Colorado State University, for assistance in identification of algae.

This report is based in part on a thesis submitted by S. P. Canton in partial fulfillment of requirements for the degree of Master of Science in Zoology in the Graduate School of Colorado State University, Fort Collins, Colorado.

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SECTION I

INTRODUCTION

The detrimental effects of drainage from coal strip-mine spoils on aquatic life have been well documented for eastern high-sulfur coal (Riley 1960, Parsons 1968, Warner 1971, Herricks and Cairns 1972, Koryak et al. 1972). However, little is known of the effects of drainage from the low-sulfur coal strip-mines in the west. Coal has been extracted from the Edna mine, adjacent to Trout Creek in northwestern Colorado, for approximately 30 years. With the increased importance of western, low-sulfur coal, the effects of drainage from these spoils on the aquatic life should be more fully elucidated. Research was undertaken to determine the effects of drainage from the spoils of Edna mine on the aquatic macroinvertebrates of Trout Creek.

Acid mine drainage (AMD) from coal mine spoils has been a major factor in the pollution of streams in West Virginia, Pennsylvania, and Ohio. Acid mine drainage occurs with the oxidation of pyritic materials found in the overburden of strip-mines as they are exposed to air. At pH values below 4.5, this oxidation can be facilitated by the bacteria *Thiobacillus ferroxidans* (iron) and *Thiobacillus thiooxidans* (sulfur). The oxidized products, chiefly ferric hydroxide and sulfate, are buffered when they enter a stream, which causes the $Fe(OH)_3$ to precipitate leaving the rocks coated with a yellow slime (Koryak et al. 1972). The problem arises when the acidic products enter a stream in quantities that cannot be buffered by the stream or other buffering compounds such as limestone and marly clay also found in the overburden (Riley 1960).

As AMD develops, with pH values below 4.0-4.5, there is a sharp drop in numbers of species in the stream with the elimination of nontolerant forms. This is often followed by an increase in standing crop of the tolerant forms resulting in a much simplified food web (Parsons 1968, Warner 1971, Koryak et al. 1972). This pattern in the macroinvertebrate community seems to be accounted for by the loss of alkalinity in natural waters below pH values of 4.2 with resultant loss of any buffering capacity (Warner 1971, Dills and Rogers 1972).

Recovery of a stream from AMD takes place in accordance with the degree of stress encountered (Herricks and Cairns 1972). This includes destruction of macrobenthic habitat by physical alteration, such as coating of the rocks with $Fe(OH)_3$ slime; the removal of an essential chemical, such as the loss of bound CO_2; and the destruction of biota through various toxic agents, especially heavy metals, which are more soluble under AMD conditions. The biotic recovery from these stresses can be a function of time with temporary stresses or a function of distance when the stress is continuous.

Goodnight (1973) and Harrel et al. (1973) indicate several reasons for using macroinvertebrates as indicators of pollution: (1) they collectively show a wide range of tolerance to a variety of pollutants; (2) their long life cycles can reflect temporary stresses difficult to detect by periodic chemical sampling; (3) their relatively low motility keeps them in the area of pollution; (4) they occupy central positions in the food web; and (5) they are easily adapted to laboratory study. The early use of invertebrates was with indicator species to classify degrees of pollution (Hynes 1960). The recent trend is to analyze pollution on the community level (Gaufin 1973). Methods for analysis of communities have been reviewed by Goodnight (1973).

SECTION II

CONCLUSIONS

1. Coal mining adjacent to Trout Creek in northwestern Colorado commenced about 30 years ago. An extensive and relatively undisturbed watershed occurs upstream from the mine spoils.

   a. With the degree of resolution applied during the present study, no detrimental effects from mining activity on the macroinvertebrate community were discernible.

   b. Increases in macroinvertebrate standing crop below the mine indicate an enrichment effect on the stream.

   c. Diversity and equitability values do not indicate stressed conditions.

2. During the two years of study, mining activity was confined to a location more than 1 km from the stream. In addition, all spoils lie at least 30 m from the stream.

   a. This strip of 30 m or more may act as a buffer zone which reduces amounts of potentially detrimental substances entering the stream.

   b. Increases in specific conductance below the mine occurred primarily during periods of high runoff (McWhorter et al. 1975) which indicate that many ions may be held in the soils of the buffer zone and move into the stream mainly during periods of groundwater "flushing."

   c. The benthic fauna seem to tolerate these relatively short periods of water quality degradation without visible effects on the community structure. Increased abundance of macroinvertebrates was in fact correlated with higher specific conductance values.

SECTION III

RECOMMENDATIONS

1. The "buffer zone" of unmined land between the mine spoils and Trout Creek should be retained and protected from other disturbances. Tributary streams, even if intermittant, should likewise be protected.

2. Physical, chemical, and biological processes which occur in the soils of the buffer strip should be investigated further to elucidate any mechanisms which improve the quality of surface or ground water traversing this zone.

3. Several ponds occur in the mine spoils and receive seepage directly from the spoils. Preliminary analyses indicate that the chemical environments of some ponds are quite different from those of others. Since remarkably little biological work has been conducted on spoils ponds in the western U.S., it is suggested that the biota of the ponds in the Edna Mine spoils be investigated in conjunction with physical and chemical analyses.

4. The practice of spoil pile contouring and revegetation should include both new spoils and old spoils.

5. The type of strip-mining operation adjacent to Trout Creek, which leaves the valley floor intact, does not appear to harm the macrobenthos of the stream and is recommended.

SECTION IV

DESCRIPTION OF THE STUDY AREA

Trout Creek basin runs roughly north-south beginning in the Dunkley Flat-Tops area and ending in the Yampa River west of Milner, Colorado. The upper portion of the basin lies in the Routt National Forest and is well vegetated with aspen and conifers. The middle portion of the watershed is a mixture of forested and farm lands. Lower portions of the basin are more xeric with sage and other woody shrubs and grasses predominating. Agricultural practices (primarily grazing) variously affect the middle and especially lower portions of the basin. The altitude in the study area ranges from 2260 to 2050 m. From 2160 to 2100 m the stream is bordered on the east by the Edna coal mine.

The coal at Edna mine is extracted from the Wadge seam in the Williams Fork unit of the Mesa Verde group. The overburden of the Williams Fork formation consists mainly of shale, thin beds of sand, and sandy shale (McWhorter et al. 1975). During the study, mining activity was located more than 1 km from Trout Creek. Strip mining leaves the overburden in large spoil piles that are at present being regraded. The spoil piles lie at least 30 m from the stream. The coal at Edna mine is low sulfur coal compared to eastern coal, but the 2.4% sulfur content and the 30.8% iron oxide in the ash are the highest values for coals studied in Colorado (Deurbrouck 1970).

Water quality data from Trout Creek, Colorado are compared to other water quality criteria in Table 1. For Trout Creek this site and date generally exhibited the maximum values for the parameters indicated. In the west, the overburden is generally low in pyritic materials and quite shaley. This provides better buffering and higher pH values than those found in areas of AMD. Trout Creek water quality exceeds the AMD criteria for total hardness and total dissolved solids due to the formations of soluble salts (e.g., sodium, calcium, bicarbonates and sulfates) in the overburden rather than from oxidized sulfides found in AMD (McWhorter et al. 1975). The high levels of sulfates in Trout Creek below the mine appear to be from the gypsum ($CaSO_4 \cdot H_2O$) found in the overburden. It should be noted that the values for Trout Creek are during spring runoff. Yet, even with increased stream flow, dilution could not compensate for the flushing of groundwater from the mine (Skogerboe 1976).

Table 2 presents the dissolved trace metals found in Trout Creek in comparison to levels lethal to an aquatic insect (Warnick and Bell 1969). For Trout Creek, this site and date generally exhibited the maximum values for the trace metals indicated. All values on Table 2 are below toxic levels

TABLE 1. WATER QUALITY DATA FROM TROUT CREEK, COLORADO, COMPARED WITH WATER QUALITY CRITERIA

Water quality criteria	Trout Creek[a]	AMD[b]	Public water supplies	Water for aquatic life
Acidity (mg $CaCO_3$/liter)	<1.0	>3.0	--	--
Alkalinity (mg $CaCO_3$/liter)	126	0.0	--	20+[c]
Alkalinity/acidity	>126	<1.0	--	--
Total hardness (mg/liter)	418	>250	--	--
Specific conductance (μmhos/cm)	640	--	--	3000[d]
Total dissolved solids (mg/liter)	509	>500	500[e]	2000[f]
Suspended solids (mg/liter)	5.5	>250	--	--
pH	7.8	<6.0	5.0-9.0[c,f]	6.5-9.0[c]
Total iron (mg/liter)	0.24	7.5	0.3[c,f]	1.0[c]
Sulfate (mg/liter)	250	>250	250[c,f]	--

[a] Site C-8, April 1976 (Skogerboe et al., in press).
[b] Herricks and Cairns (1972).
[c] U.S. Environmental Protection Agency (1976).
[d] McKee and Wolf (1963).
[e] U.S. Public Health Service (1962).
[f] National Academy of Science-National Academy of Engineering (1973).

TABLE 2. TRACE METALS FOUND IN WATERS OF TROUT CREEK, COLORADO, COMPARED TO REPORTED TOXIC LEVELS

Trace metals	Trout Creek[a]	Median toxic level for *Ephemerella*[b]
Zinc	0.007 mg/liter	16.0 mg/liter @ 10 days
Iron	<0.02 μg/liter	0.32 mg/liter @ 96 h
Nickel	0.007 mg/liter	4.0 mg/liter @ 96 h
Mercury	<0.03 μg/liter	2.0 mg/liter @ 96 h
Copper	<0.005 mg/liter	0.32 mg/liter @ 96 h

[a]Site C-2, April 1976 (site and date of generally maximum values for the trace metals indicated) (Skogerboe et al., in press).

[b]Warnick and Bell (1969).

reported by Warnick and Bell for *Ephemerella*. One should note that site C2 was above most mining activity. Although not shown in the table, values for the trace metals generally decreased downstream, which may be partially due to precipitation associated with increased pH. Skogerboe (1976) also found that trace element concentrations were considerably higher in the sediment of runoff beds in the mine than in the sediment of Trout Creek and postulated that as the water flows across the strip of unmined land ... "those elements contained in the runoff are largely removed from solution, perhaps by precipitation, before the runoff reaches the creek." At site C2 (April 1976) the water temperature was 0°C, the pH 7.5, the alkalinity 110 mg/liter $CaCO_3$, and the hardness 131 mg/liter $CaCO_3$. Warnick and Bell used filtered Lake Superior water at 18.5°C, with pH ranging from 6.9 to 8.2, alkalinity from 30 to 54 mg/liter $CaCO_3$, and hardness from 40 to 54 mg/liter $CaCO_3$.

Six study sites were established July 1975 to correspond to a gradient of mining activity (Figure 1). Five of these correspond to chemical sampling locations of McWhorter et al. (1975). An additional sampling site (C9) was added September 1975 3 km downstream from site C8.

(1) Site C0: 2260 m. This upstream sampling site had a substratum of rubble with sand and gravel underneath. The riparian vegetation is mainly willows and other woody vegetation which shade the creek.

(2) Site C1: 2254 m. This was the upstream sampling site of McWhorter et al. (1975). It has large rubble substratum with gravel and sand underneath. The stream narrows making the channel deeper and swifter than at site C0. The vegetation is woody with some open areas of grass providing less shade than at site C0.

(3) Site C2: 2208 m. This is immediately above the Edna mine and at this point the stream leaves a narrow valley and enters a flood plain. The substratum is rubble with sand and gravel underneath. Riparian vegetation is mainly willows providing shade for the creek.

(4) Site C4: 2150 m. This site is above the present mining operation and immediately below the old mine spoils where mining ceased approximately 18-20 years ago. The substratum is rubble with gravel and sand underneath. The sand is more prominent here due to erosion of the sandy west bank. The vegetation is woody plants and grasses.

(5) Site C6: 2140 m. This site is near the downstream limit of the mine. The substratum is rubble with sand and gravel underneath. Sand is deposited on the inside of meanders near the site. The riparian vegetation is willows and grasses and some effects of grazing are apparent on the banks of the stream.

(6) Site C8: 2138 m. This site is immediately below the present mining activity. The east bank is very steep with shale and sand eroding from the side. The substratum is made up of large slabs of shale and rubble. Gravel and sand are underneath. Riparian vegetation of willows and grasses provides some shade for the creek.

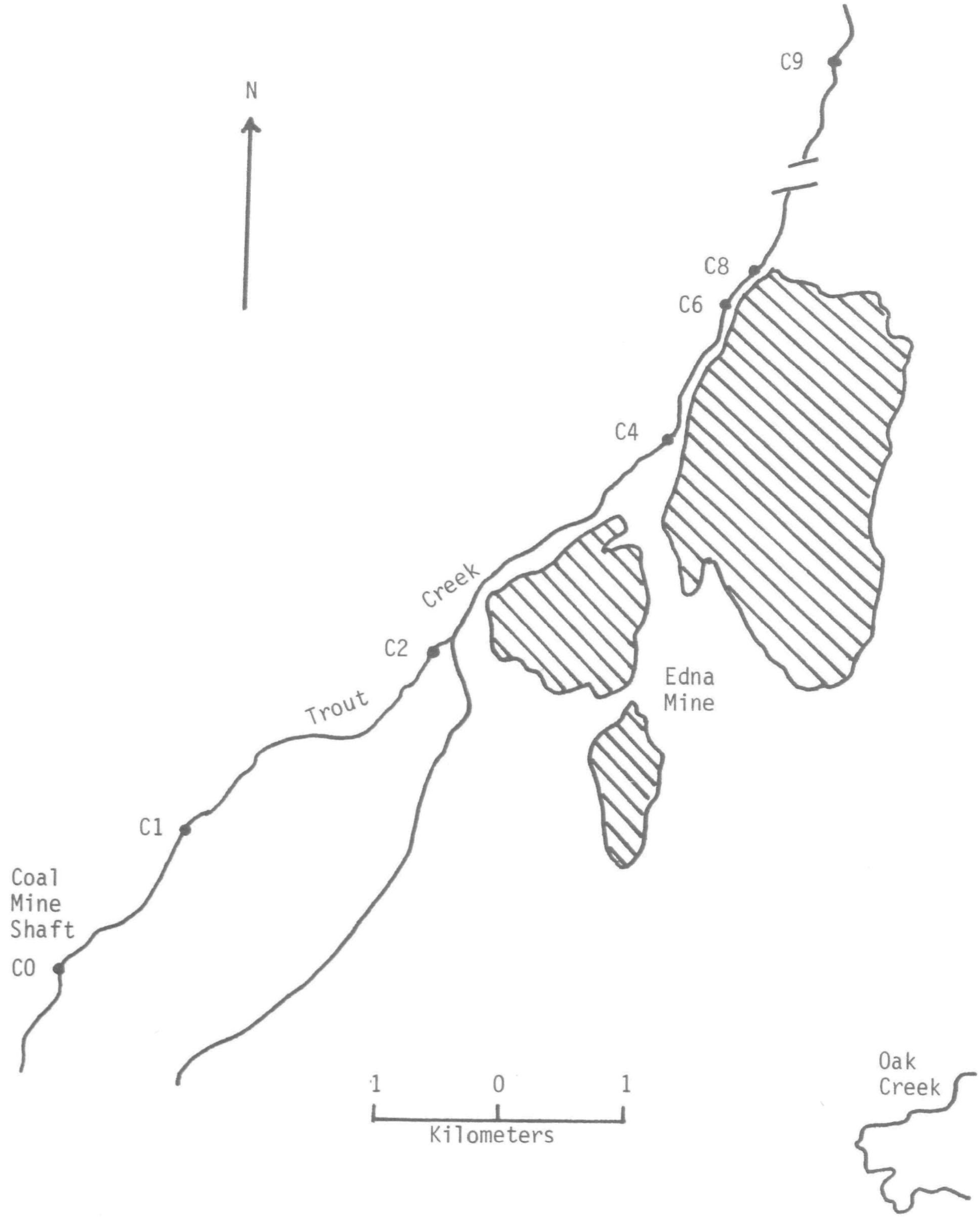

Figure 1. Sampling stations and mine spoils at Trout Creek, Colorado. Mine spoils indicated by crosshatching.

(7) Site C9: 2050 m. This site is located 3 km downstream from site C8 at a point where the valley broadens. The substratum is rubble with sand and gravel underneath. There are considerably more fines, especially silts, in the substratum than at the other sites. The low banks are primarily sand and clay. Increased grazing leaves mainly grasses on the bank, providing little shade.

SECTION V

METHODS

Trout Creek was sampled monthly from July 1975 through April 1977. However, due to inclement weather or high water, it was not possible to sample sites C6 and C8 in December 1975, site C4 in January 1976, or site C8 in June 1976. Mining activity relocated during the second year of study and only sites C2 and C4 were sampled from July 1976 to April 1977 to cover the area above and below the drainage from the new mining activity. Using a Surber square-foot sampler with a mean mesh size of 700 μm, five or six samples were taken at each site on rubble substratum in the riffle sections of the stream. From January 1977 to April 1977, 8 to 10 samples were taken with a modified Surber sampler (based on Lane 1974). This sampler encloses an area of 0.04 m^2, has a screened front to reduce inflow of leaves and twigs, enclosed sides to reduce loss of benthic organisms from backwash, and a net with mean mesh size of 700 μm. The organisms collected were stored in 5% formalin and subsequently sorted from the debris and placed in 80% ethanol. The contents of each sample were stored and enumerated separately to allow for future statistical analysis of variance within and between sites. Biomass (wet weight) was determined by volumetric displacement in a graduated centrifuge tube (assuming a specific gravity for the invertebrates of 1.0, a close approximation). With excessively large samples, subsamples were taken.

Identifications to the generic (and in some cases specific) level were based upon the keys of Pennak (1953), Usinger (1956), Edmondson (1959), Mason (1973), Baumann (1975), and Wiggins (1977). Other species identifications were based upon Smith (1968) for *Rhyacophila* (larvae); Allen and Edmunds (1959, 1961, 1962, 1963, 1965) for *Ephemerella* (nymphs); Jensen (1966) for *Ameletus* (nymphs); Gaufin et al. (1972) for *Arcynopteryx* (adults); Brown (1972) for the Elmidae beetles (adults); and Usinger (1956) for *Brachycentrus* (adults) and *Simulium* (pupae). Because all Simuliidae pupae were *Simulium arcticum*, all simuliids were designated *S. arcticum* even though it was not possible to identify the larvae. The *Arcynopteryx parallela* species designation was based upon identification of adults collected at the stream margin.

The Shannon-Weaver index used by Wilhm and Dorris (1968) was used to calculate macroinvertebrate diversity. The index is derived from the equation: $\bar{d} = -\Sigma n_i/N\ (\log_2 n_i/N)$ where N = total number of individuals and n_i = number of individuals in the i^{th} species. One of the greatest strengths of the index is its flexibility. Because rare species play a minor role in determining the index value, the index should give a good measure of community structure when a majority of the species present are collected (Wilhm and Dorris 1968). The Shannon-Weaver species diversity index is dimensionless and biomass units have been used instead of density values with a corresponding change in the interpretation (Wilhm 1968). Species diversity index calculations were made with the computational formula as follows: $\bar{d} = C/N\ (N\log_{10}N - \Sigma n_i \log_{10} n_i)$ where N = total number of individuals, n_i = number of individuals in the i^{th} species, and C = 3.32 converting $\log_2$ to $\log_{10}$ (Weber 1973).

Equitability, a component of species diversity, is computed from the equation: s'/s where s = number of species and s' = derived number of species calculated from a table based upon MacArthur's model (Lloyd and Ghelardi 1964). This value may be more sensitive to differences in samples than the species diversity index (Weber 1973).

Statistical analysis of variance was calculated on $\log_{10}$ transformations of the raw density data (organisms/sample prior to conversion to per meter square values) to allow use of parametric tests (Elliott 1973).

SECTION VI

RESULTS AND DISCUSSION

A. YEAR ONE: JULY 1975 TO JUNE 1976

1. Macrobenthos

During the first year of study, 88 taxa were identified at the seven sites on Trout Creek (Appendix A), although only 27 were numerically abundant.

The mean standing crop, all sites and dates combined, was 3713.8 organisms and 17.2 g per m^2. This placed Trout Creek in the "rich" category using U.S. Fish and Wildlife standards (Madsen 1935). Annual mean density showed a general increase downstream with a range of 2178 to 7089 organisms/m^2 (sites C1 and C9, respectively). Biomass annual means exhibited a similar trend (Table 3) with a range in values of 11.7 to 31.4 g/m^2 (sites C1 and C9, respectively). In general, there was a drop in standing crop from C0 to C1 (Figure 2) with a subsequent rise at C2. There was a slight decrease at C4 followed by a general increase through C9, except for a drop in biomass at C8 due to decreases in Trichoptera and Ephemeroptera biomass. The sharp rise at C9 was due primarily to the extreme richness at this site for the November sampling date (20,000 organisms/m^2).

Aquatic insects comprised over 90% of the annual mean standing crop at all sites (Table 4) and thus determined much of the downstream pattern (Figure 3). The drop at C1 was due mainly to decreases in Trichoptera. Decreases in abundance of *Lepidostoma* sp., *Agapetus* sp., *Oligophlebodes* sp., and elmid beetles (*Optioservus seriatus* and *Zaitzevia parvula*) overwhelmed the slight increase in *Brachycentrus americanus, Atherix variegata, Simulium arcticum*, and Chironomidae. The increase at C2 occurred in all major groups. *Hydroptila* sp. increased in abundance at this site and made up for the loss of numbers of *Oligophlebodes* sp. All major groups except Trichoptera decreased at C4. The large increase in numbers of *Agapetus* sp. and *Hydropsyche* sp. was overshadowed by an equally large decrease in *Brachycentrus americanus, Lepidostoma* sp., *Hydroptila* sp., *Baetis* sp., *Brachyptera* sp., and *Cricotopus* sp. These are all major components of their respective faunal groups. Increases in all major genera, except *Simulium arcticum* and *Rhithrogena* sp., accounted for the increased standing crop at site C6. At site C8, there was again a general further increase in the major genera, but decreases in *Glossosoma* sp. and *Rhithrogena* sp. resulted in a slight decrease in biomass. Increases in *Hydropsyche* sp., *Ephemerella inermis, Baetis* sp., and *Orthocladius* sp. coupled with tremendous increases in *Atherix variegata,*

TABLE 3. MEAN BIOMASS VALUES[a/] FOR MAJOR TAXA FROM TROUT CREEK, COLORADO, JULY 1975 TO JUNE 1976

Taxa	C0	C1	C2	C4	C6	C8	C9
Trichoptera	6.5	3.3	4.3	5.1	11.3	10.6	13.0
Diptera	2.5	2.1	2.5	1.8	1.7	1.8	9.4
Ephemeroptera	2.7	3.3	3.0	2.8	4.0	2.6	2.2
Plecoptera	2.6	2.7	2.5	1.3	3.5	4.2	2.9
Coleoptera	0.9	0.5	0.9	0.4	1.0	0.9	1.9
Hemiptera	--	+[b/]	--	+	+	+	+
Odonata	--	--	--	--	--	+	--
Acari	+	+	+	+	+	+	+
Mollusca	0.2	+	0.1	0.1	0.8	0.4	1.3
Oligochaeta	+	+	+	+	+	0.1	0.6
Nematoda	+	+	+	+	+	+	+
Turbellaria	+	--	--	--	--	--	--
Total	16.1	11.7	14.1	11.8	22.3	19.9	31.4

[a/] g/m^2 wet weight based upon volumetric conversion.

[b/] + = present but less than 0.1 g/m^2.

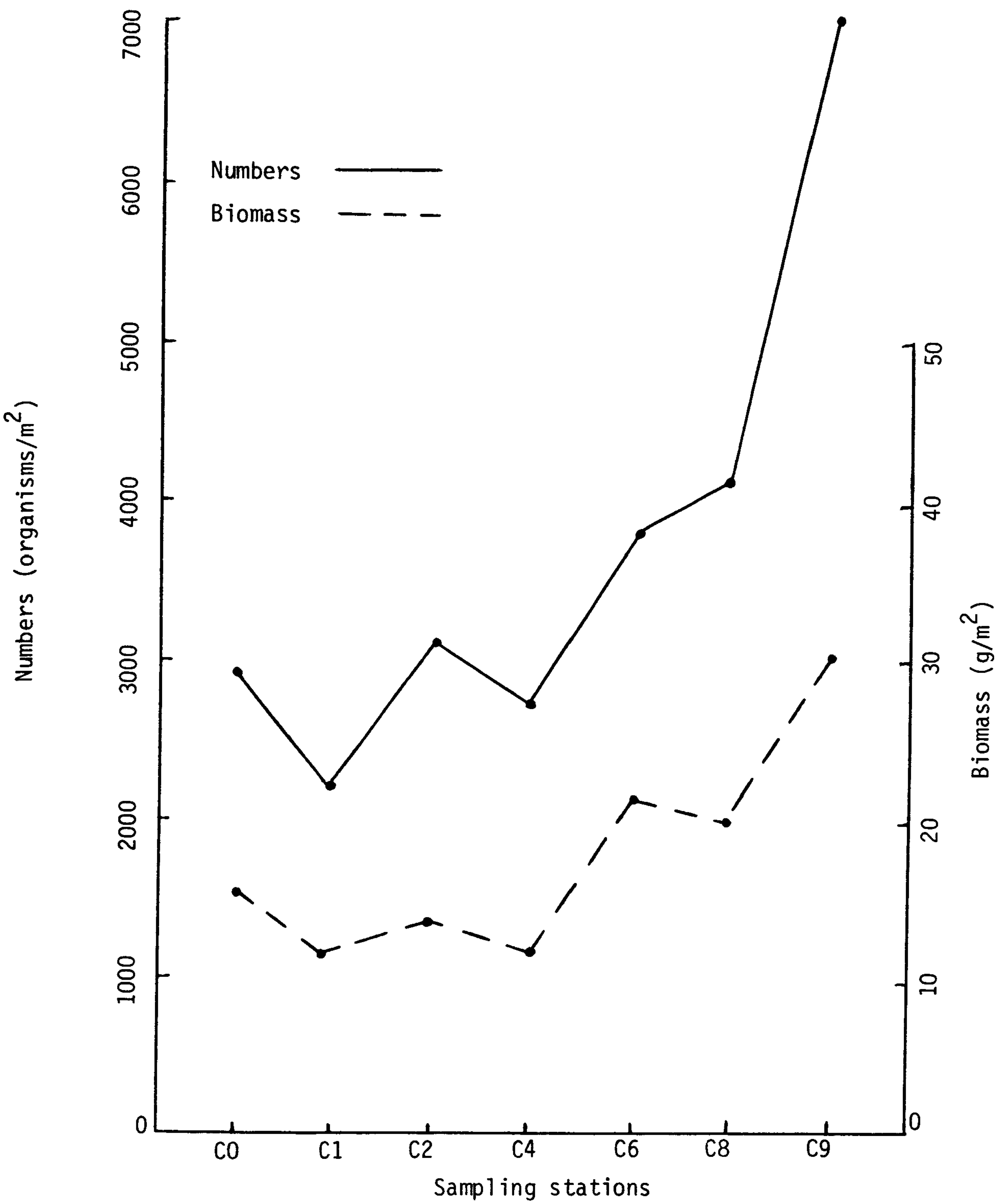

Figure 2. Mean standing crop of benthic macroinvertebrates in Trout Creek, Colorado, July 1975 to June 1976.

TABLE 4. MEAN PERCENTAGE COMPOSITION OF THE FIVE MAJOR INVERTEBRATE GROUPS BY DENSITY AND BIOMASS FOR TROUT CREEK, COLORADO, JULY 1975 TO JUNE 1976

Taxa	C0	C1	C2	C4	C6	C8	C9	All sites
				Density				
Trichoptera	50	28	29	55	55	53	33	42
Diptera	13	27	22	12	8	15	33	20
Ephemeroptera	13	22	22	19	20	16	16	17
Plecoptera	5	6	9	3	4	4	2	4
Coleoptera	18	14	17	9	11	10	14	14
Total	99	97	99	98	98	98	98	97
				Biomass				
Trichoptera	40	28	34	43	51	53	41	44
Diptera	16	17	18	15	8	9	30	17
Ephemeroptera	17	28	21	24	18	13	7	16
Plecoptera	16	22	18	11	16	20	9	15
Coleoptera	6	4	6	3	4	4	6	5
Total	95	99	97	96	97	99	93	97

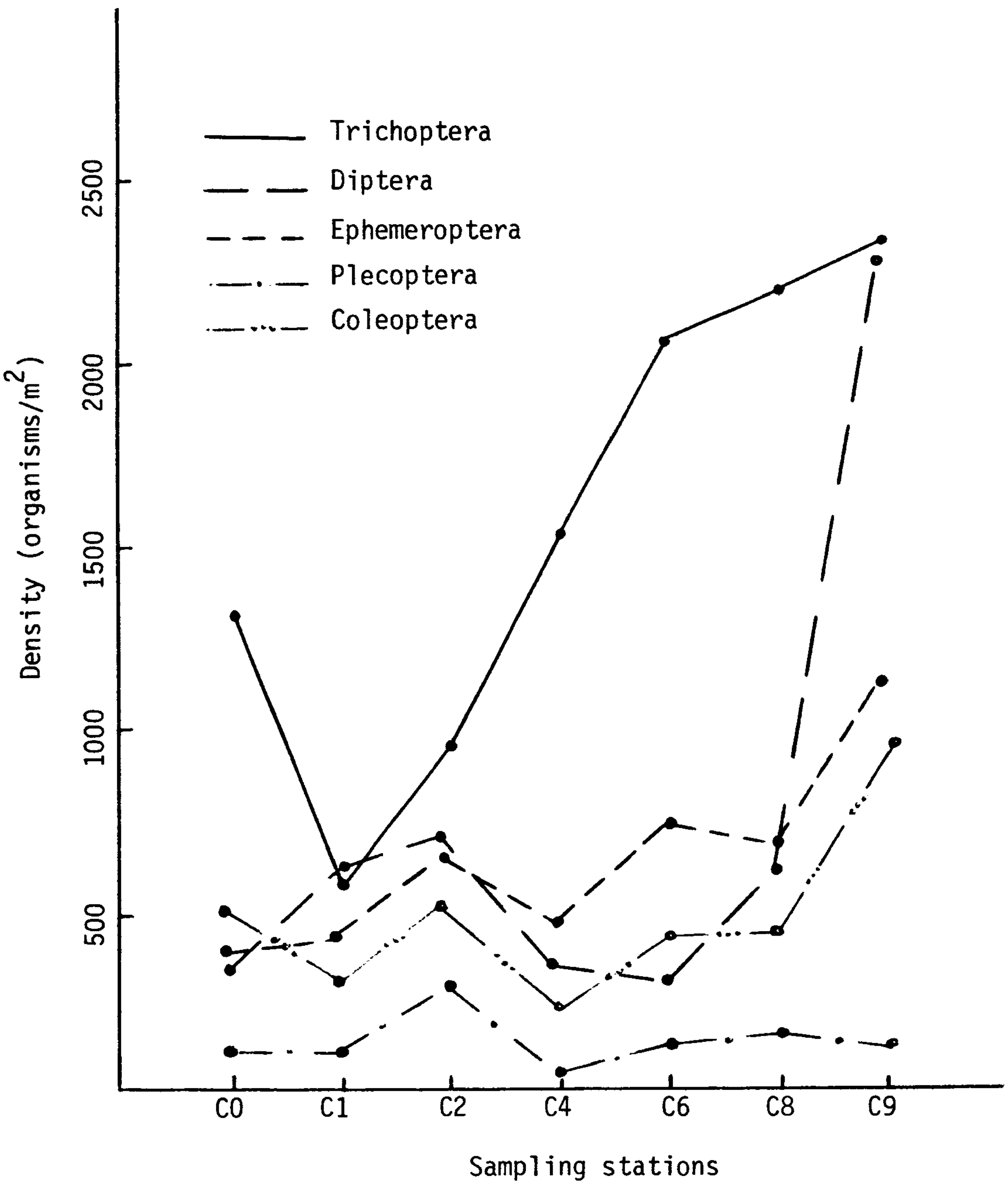

Figure 3. Mean density for the five major invertebrate groups from Trout Creek, Colorado, July 1975 to June 1976.

Simulium arcticum, *Microtendipes* sp., *Helicopsyche* sp., and *Cheumatopsyche* sp. accounted for the sharp rise in standing crop at site C9, more than compensating for the dramatic decreases in *Brachycentrus* sp., *Agapetus* sp., and *Rhithrogena* sp.

Much of the downstream pattern in density was determined by relatively few taxa. From 55% to 83% of the density was the result of eight taxa at each site (Table 5). Most of these eight taxa were among the top eight in abundance at many of the sites with *Baetis* sp. being among the top eight at all the sites.

Generally the trend showed an increase in numbers of organisms and biomass in the downstream direction. This is a common occurrence in streams (Hynes 1970), although normally not to the degree seen here. The increase could also be due to an enriching effect of the agricultural practices near the stream (e.g., grazing and irrigation return water). Chemical changes in the stream through the study area could also affect the density and biomass. Specific conductance increased in the study area during the first year of study (Table 6) and was positively correlated with density ($r = 0.9$) and biomass ($r = 0.8$). Another factor may have been the increased hardness in the stream below the entrance of groundwater from the mine spoils (McWhorter et al. 1975), which has been postulated as a factor in increased productivity (Hynes 1970).

Statistical analysis of variance was run on the raw numbers of organisms per sample for the year's data (with $\log_{10}$ transformation) in an attempt to determine the strength of the trend seen above. The results of the analysis (Table 7) showed a significant difference between the sites (at 0.01 level), which supports the trend discussed.

2. Macrobenthic composition

Aquatic insects comprised over 83% of the total number of taxa found during the first year of the study on Trout Creek, with Trichoptera and Diptera making up 56% of the insect species. Trichoptera accounted for 42% of the numbers of individuals and 44% of the biomass for all sites combined (Table 4). Diptera comprised 20% of the density and 17% of the biomass with the Ephemeroptera making up 17% of the density and 15% of the biomass. Plecoptera accounted for 4% of the density but 16% of the biomass, while the Coleoptera comprised 14% of the density but only 5% of the biomass.

The number of species remained rather constant at all the sites with a drop at C9 (Table 8). This drop in numbers of species with the increased standing crop at C9 may point to a slightly stressed community at this site. The greater numbers of species at C8 was mainly due to increased diversity of Trichoptera. The lower numbers of species at C9 resulted from fewer species of Trichoptera, Diptera, and Ephemeroptera.

The number of species of Trichoptera remained fairly constant at the sites, with a higher value at C8 due to increased numbers of rare species. *Oligophlebodes* sp. was restricted to upper sites while *Cheumatopsyche* sp. was predominately restricted to the lower sites. The other genera varied in

TABLE 5. MAJOR TAXA[a] AND PERCENTAGE OF TOTAL DENSITY, TROUT CREEK, COLORADO, JULY 1975 TO JUNE 1976

Taxa	C0	C1	C2	C4	C6	C8	C9
Brachycentrus americanus	X	X	X	X	X	X	
Lepidostoma sp.	X		X				
Agapetus sp.	X	X	X	X	X	X	
Oligophlebodes sp.	X						
Hydropsyche sp.				X	X	X	X
Cheumatopsyche sp.							X
Orthocladius sp.		X				X	X
Cricotopus sp.		X	X				
Eukiefferiella sp.						X	
Atherix variegata							X
Simulium arcticum				X			X
Baetis sp.	X	X	X	X	X	X	X
Rhithrogena sp.	X	X	X	X	X	X	
Ephemerella micheneri							X
Alloperla sp.					X		
Prostoia besametsa			X				
Optioservus seriatus	X	X		X	X	X	X
Zaitzevia parvula	X	X	X	X			
Percentage of total	55	63	75	83	75	73	70

[a] Eight most abundant taxa at each site.

TABLE 6. MEAN STANDING CROP FOR THE SAMPLING SITES ON TROUT CREEK, COLORADO, COMPARED TO MEAN SPECIFIC CONDUCTANCE, JULY 1975 TO JUNE 1976

Density, biomass, specific conductance	C0	C1	C2	C4	C6	C8	C9
Density (organisms/m^2)	2929.5	2177.9	3146.4	2729.5	3800.4	4124.1	7088.6
Biomass (g/m^2)	16.1	11.7	14.1	11.8	22.3	19.9	31.4
Specific conductance (μmhos/cm)[a]		145.8	144.9	250.0	288.0	288.0	1530.0

[a] R. K. Skogerboe (unpublished data).

TABLE 7. ANALYSIS OF VARIANCE TABLE FOR THE SAMPLING SITES ON TROUT CREEK, COLORADO, JULY 1975 TO JUNE 1976

Source of variation	Sum of squares	Degrees of freedom[a/]	Mean square	F-ratio
Between sites	1.17	6	0.200	4.4[b/]
Within sites	3.16	70	0.045	
Total	4.33	76		

[a/]Based upon unequal sample size.

[b/]Significant at the 0.01 level.

TABLE 8. NUMBER OF SPECIES IN EACH MAJOR TAXON FOR THE SAMPLING SITES ON TROUT CREEK, COLORADO, JULY 1975 TO JUNE 1976

Taxa	C0	C1	C2	C4	C6	C8	C9
Trichoptera	13	12	12	13	13	17	12
Diptera	16	14	18	14	14	15	13
Ephemeroptera	10	10	10	10	11	11	8
Plecoptera	7	10	9	8	9	7	7
Coleoptera	5	5	5	9	6	6	2
Hemiptera	0	1	0	1	1	1	1
Odonata	0	0	0	0	0	1	0
Hydracarina	4	4	4	4	4	3	3
Mollusca	3	3	2	2	3	4	4
Oligochaeta	1	1	1	1	1	1	2
Nematoda	1	1	1	1	1	1	1
Turbellaria	1	0	0	0	0	0	0
Total	61	61	62	63	62	67	53

abundance throughout the study area with no one species predominant at all the sites. There is an increase in the net-spinning caddisflies, *Hydropsyche* sp., and *Cheumatopsyche* sp. at the downstream sites, possibly due to increased suspended matter below the mine. Temperature was apparently not the factor restricting the abundance of *Oligophlebodes* sp. or *Cheumatopsyche* sp. since values were rather constant at the sites (Table 9).

Dipteran species were also similar at all sites, with C0 and C2 having the greatest number of species, due to the larger number of chironomids. Again, no species was abundant at all sites, though certain species show an increase at the lower sites (*Atherix variegata, Simulium arcticium, Orthocladius* sp., and *Microtendipes* sp.). This increase was probably due to the increased particulate matter in the stream below the mine (e.g., *Simulium arcticum*, a filterfeeder) or the siltier substrata at the lower sites.

Rather constant numbers of ephemeropteran species were prevalent. None of the species was very abundant at all the sites, but most species occurred at all sites. *Ephemerella inermis* and *E. micheneri* showed a marked increase at the lower sites.

Plecoptera exhibited a greater number of species at the upstream sites. This was due to the winter stoneflies, *Zapada* sp., *Paraleuctra sara*, and *Leuctra glabra*. Other stoneflies occurred throughout the study area.

Two species comprised the vast majority of the Coleoptera found in Trout Creek. The larvae and adults of *Optioservus seriatus* and *Zaitzevia parvula* were important at all sites. *O. seriatus* increased in abundance downstream, while *Z. parvula* decreased in numbers at the lower sites.

Hemiptera and Odonata were found only occasionally, mainly at the sites adjacent to or below the mine. They may have come from ponds in the mine spoils.

The number of species of Hydracarina was quite constant at all sites and it was numerically most abundant at the upper sites. Only *Mideopsis* sp. showed an increase at the lower sites.

The number of molluscan species increased slightly at the downstream sites and was highest at C6. Here *Physa* sp. was dominant; *Ferrissia* sp. was most abundant at C9. All of the genera found are widespread in their distribution in North America (Clench 1959).

Only two species of Oligochaeta were identified. *Limnodrilus* sp. was found only at C9 and was relatively abundant. A few specimens of the large lumbricid earthworm, *Eiseniella tetraedra*, were collected, but were probably accidentals which washed in from the stream banks (Ward 1976).

Nematoda occurred infrequently and could not be properly identified.

TABLE 9. MEAN TEMPERATURE AND RANGE OF TEMPERATURE AT THE SAMPLING SITES TROUT CREEK, COLORADO (°C), JULY 1975 TO JUNE 1976

Temperature	C0	C1	C2	C4	C6	C8
Mean temperature	5.6	5.7	5.1	6.4	6.2	5.1
Range of temperature	0.0-16.0	0.0-16.0	0.0-16.5	0.0-17.5	0.0-17.5	0.0-18.0

3. Diversity

Diversity did not show the downstream pattern seen with standing crop (Table 10). Although the mean number of species at the sites was similar, the composition did change from site to site. Diversity index and equitability values were similar at all sites with the range of values masking any differences between sites. The within site range of values partly represented seasonal changes resulting from life history phenomena. As life histories of the various stream macrobenthos progress, the species diversity index fluctuates. These fluctuations are enhanced by sampling, since the sampling efficiency is partially a function of life cycle stages of the organisms. At undisturbed locations, this fluctuation should be seasonal showing definite periodicity; whereas at disturbed sites, the fluctuations become random (Dills and Rogers 1972). However, values varied somewhat randomly at all the Trout Creek sites. The average diversity index values at the sites on Trout Creek fall essentially within the "normal" range defined by Wilhm (1970).

4. Seasonal trends

Seasonal density, all sites combined, ranged from 1813 organisms/m^2 in June 1976 to 6451 organisms/m^2 in November 1975. Density peaked in November and April (Figure 4). Biomass values ranged from 9.7 in May 1976 to 29.8 g/m^2 in November 1975 (Table 11). The seasonal pattern of density was followed closely by the biomass. Diversity, however, was relatively constant throughout the year.

The sites differed in their seasonal trends (Figure 5). Sites C0 and C4 seemed to fluctuate somewhat randomly providing little contribution to the peaks in fall and spring. The fall peak seemed to be largely due to the extreme abundance found at C9 in November; while the spring peak occurred at both C9 and C2.

The pattern exhibited in Figure 4 can be explained by examination of the seasonal trends for the five major invertebrate groups (Table 12 and Figure 6). The increase in fall was apparent for all the groups with few aberrations. The drop in the Trichoptera density in August was due in part to decreased density of *Brachycentrus americanus*, *Lepidostoma* sp., and *Hydroptila* sp. (Table 13), which may emerge at this time. The decrease of Ephemeroptera in September was due mainly to the large drop in *Baetis* sp. abundance. The sharp decline in standing crop in December occurred in most major genera. Only *Oligophlebodes* sp. and *Cricotopus* sp. increased in numbers at this time. The increase to the spring peak in April was not as consistent as that seen in the fall. Trichoptera, Diptera, and Coleoptera continued to decrease from December to January, especially *Lepidostoma* sp., *Hydropsyche* sp., *Cheumatopsyche* sp., *Orthocladius* sp., *Cricotopus* sp., and *Zaitzevia parvula*. Ephemeroptera and Plecoptera increased during this period with *Rhithrogena* sp. and *Alloperla* sp. showing the greatest change. The general increase in February occurred especially in *Agapetus* sp., *Hydropsyche* sp., *Cricotopus* sp., *Eukiefferiella* sp., *Prostoia besametsa*, and *Optioservus seriatus*. A decrease in the abundance of *Rhithrogena* sp. accounted for the

TABLE 10. MEAN NUMBER OF TAXA AND THE RANGE OF VALUES FOR THE SHANNON-WEAVER INDEX AND EQUITABILITY FOR THE SITES ON TROUT CREEK, COLORADO, JULY 1975 TO JUNE 1976

Number, index, equitability	C0	C1	C2	C4	C6	C8	C9
Mean number of species	33	30	32	30	33	36	34
Shannon-Weaver Index	3.1-4.1	2.6-3.9	2.3-3.8	2.5-3.8	2.4-3.8	2.6-4.0	2.9-4.0
Equitability	0.42-0.80	0.30-0.66	0.20-0.86	0.30-0.61	0.27-0.62	0.26-0.64	0.37-0.68

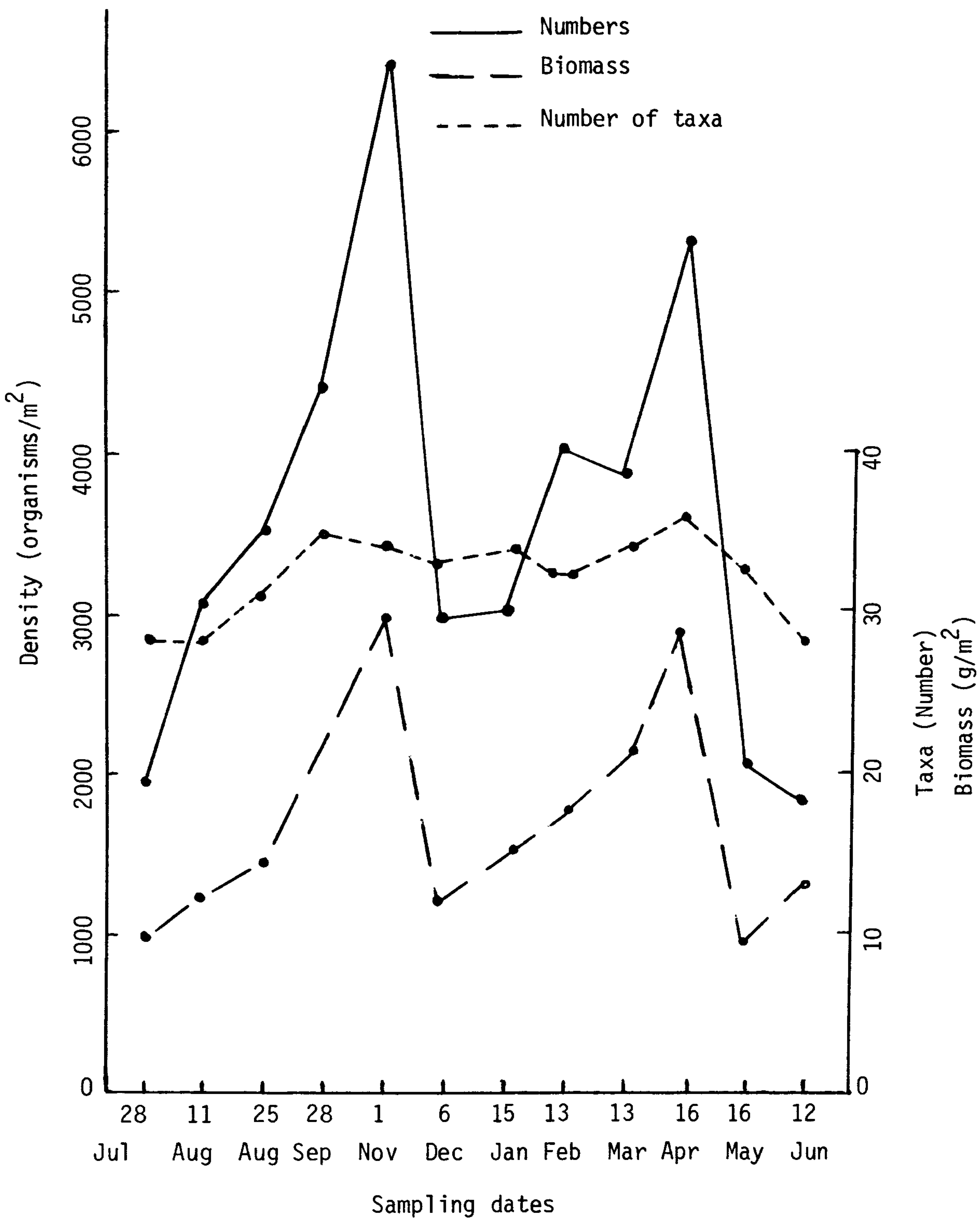

Figure 4. Seasonal trends in macroinvertebrate diversity, density, and biomass at Trout Creek, Colorado, July 1975 to June 1976, plotted as means of all sites combined.

TABLE 11. SEASONAL VALUES IN MACROINVERTEBRATE STANDING CROP AND NUMBER OF SPECIES AT TROUT CREEK, COLORADO, JULY 1975 TO JUNE 1976, MEANS OF ALL SITES COMBINED

Density, biomass, species	28 July	11 Aug.	25 Aug.	28 Sept.	1 Nov.	6 Dec.	15 Jan.	13 Feb.	13 March	16 April	16 May	12 June
Density (organisms/m^2)	1830	3045	3485	4384	6451	2862	2990	4049	3866	5302	2039	1813
Biomass (g/m^2)	9.8	12.0	14.2	21.6	29.8	12.2	14.8	17.6	21.7	29.6	9.7	13.7
Mean species	28	28	31	35	34	33	34	32	34	36	33	28

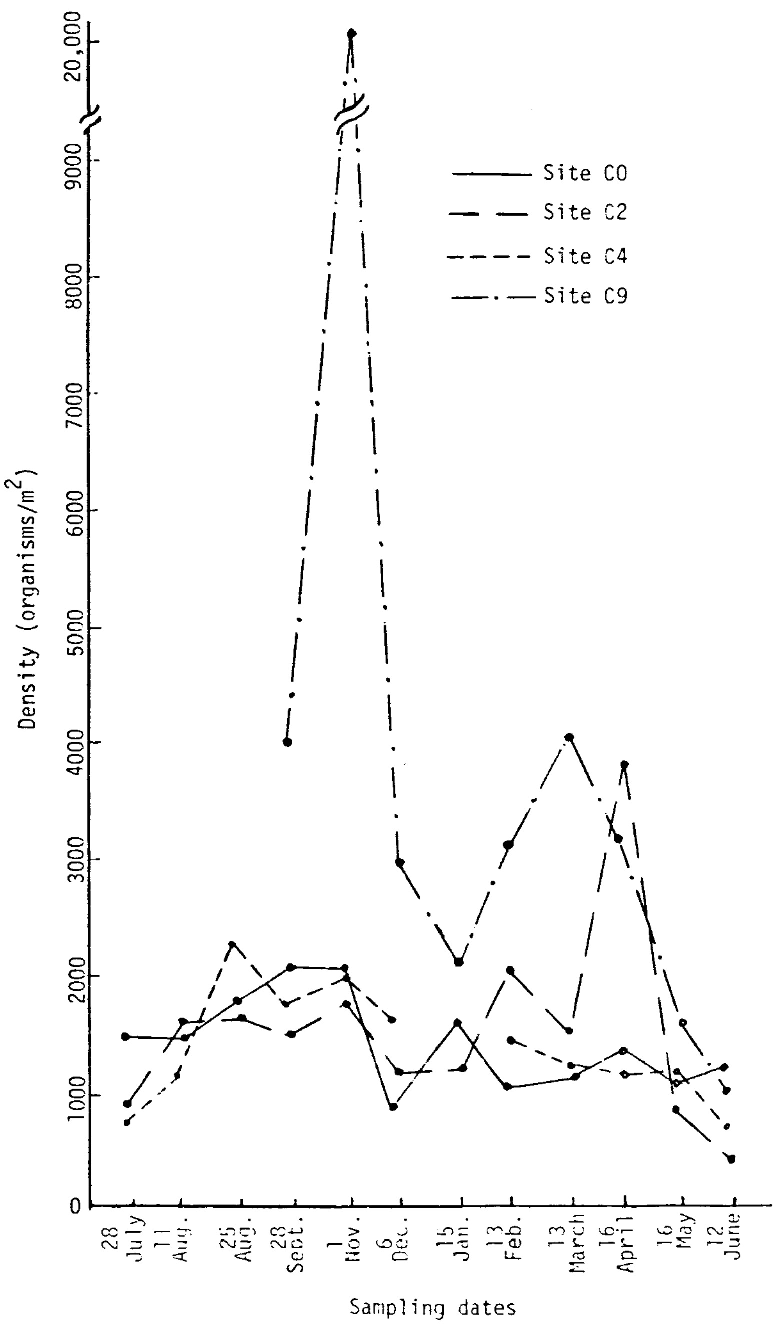

Figure 5. Seasonal trends in mean macroinvertebrate density for sites C0, C2, C4, and C9 on Trout Creek, Colorado, July 1975 to June 1976.

TABLE 12. MEAN DENSITY (ORGANISMS/M^2) OF THE FIVE MAJOR INVERTEBRATE GROUPS ON THE SAMPLING DATES (JULY 1975 TO JUNE 1976) FOR TROUT CREEK, COLORADO

Taxa	28 July	11 Aug.	25 Aug.	28 Sept.	1 Nov.	6 Dec.	15 Jan.	13 Feb.	13 March	16 April	16 May	12 June
Trichoptera	1344	1805	1248	1780	2771	1405	1317	1648	1469	2056	720	751
Diptera	157	357	771	788	1226	516	432	983	882	1362	445	273
Ephemeroptera	93	316	891	699	1265	529	719	709	792	854	349	409
Plecoptera	32	87	84	193	338	90	207	255	269	359	47	29
Coleoptera	200	468	492	868	917	301	250	395	409	474	396	208
Total	1830	3045	3485	4384	6451	2862	2990	4049	3866	5302	2039	1813

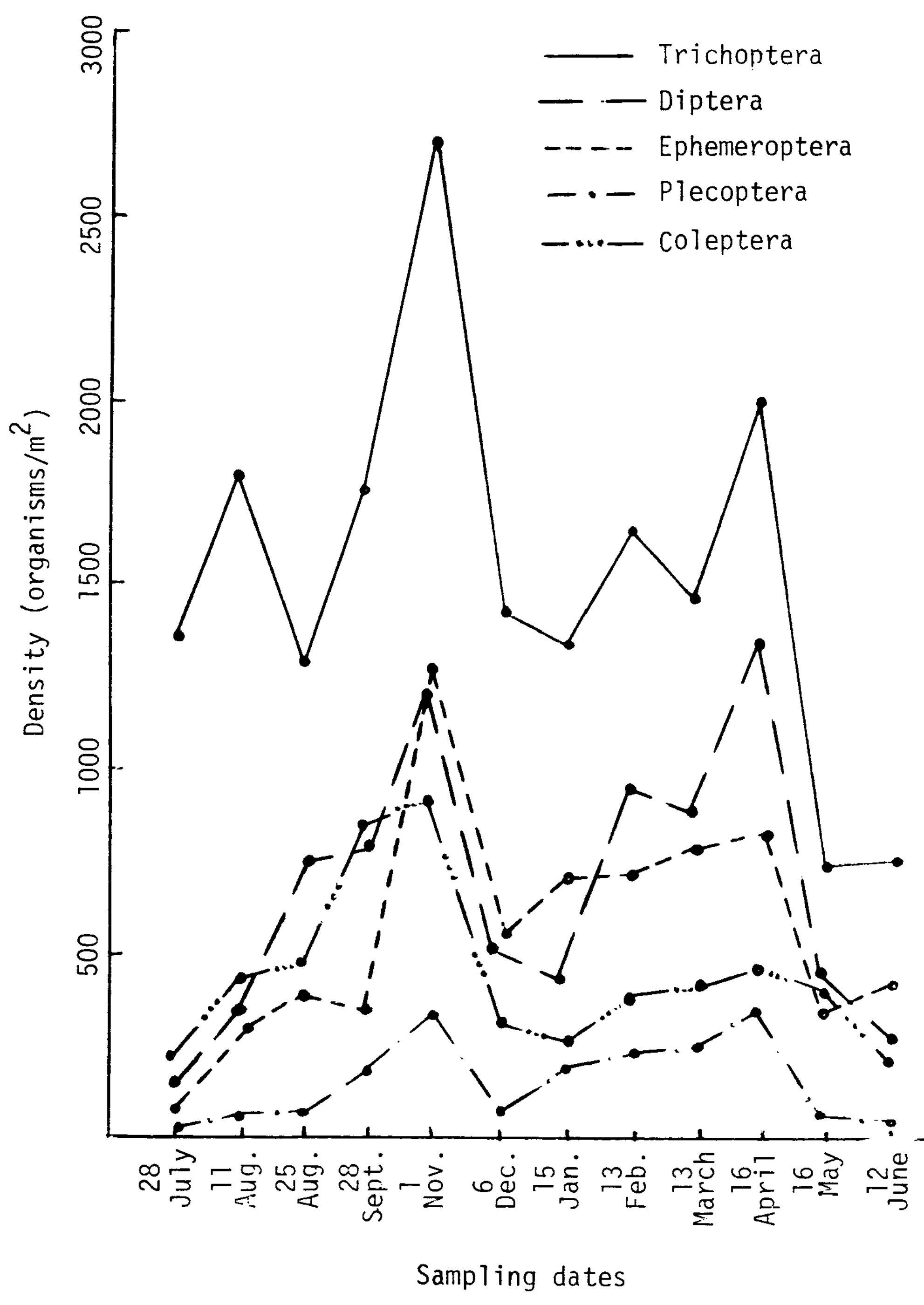

Figure 6. Seasonal trends in the five major invertebrate groups in Trout Creek, Colorado, July 1975 to June 1976, plotted as means of all sites combined.

TABLE 13. SEASONAL TRENDS FOR THE MAJOR GENERA ON THE SAMPLING DATES (JULY 1975 TO JUNE 1976), TROUT CREEK, COLORADO (ORGANISMS/M^2)

Taxa	28 July	11 Aug.	25 Aug.	28 Sept.	1 Nov.	6 Dec.	15 Jan.	13 Feb.	13 March	16 April	16 May	12 June
Brachycentrus americanus	301	292	68	161	610	144	146	176	301	1055	252	253
Lepidostoma sp.	53	139	90	140	248	111	58	63	44	141	67	79
Agapetus sp.	701	979	800	660	512	333	474	667	481	512	184	189
Glossosoma sp.	--	--	10	27	58	57	86	65	157	119	92	177
Hydropsyche sp.	8	29	184	355	561	268	132	335	257	281	88	36
Cheumatopsyche sp.	--	--	--	301	635	312	172	158	174	162	16	7
Oligophlebodes sp.	--	--	12	36	48	129	216	67	95	59	4	+[a]
Hydroptila sp.	90	246	31	4	26	5	1	37	9	9	8	+
Atherix variegata	17	26	28	97	163	48	49	56	115	79	24	14
Simulium arcticum	51	87	339	255	57	4	82	16	314	11	38	104
Orthocladius sp.	5	31	204	270	522	250	130	140	30	367	112	72
Cricotopus sp.	9	13	237	27	8	139	60	225	131	429	51	22
Eukiefferiella sp.	27	117	29	41	309	1	34	280	46	150	18	--
Baetis sp.	78	264	557	30	234	107	199	242	252	320	172	188
Rhithrogena sp.	+	55	236	506	454	245	341	174	227	175	52	45
Prostoia besametsa	--	--	--	--	--	3	27	126	115	223	16	+
Alloperla sp.	8	15	20	75	128	54	133	92	120	97	24	24
Optioservus seriatus	83	225	259	577	691	182	166	322	316	417	169	97
Zaitzevia parvula	131	225	231	282	220	114	83	72	91	115	195	112

[a] + = present but less than 1.0 organisms/m^2.

slight drop in the Ephemeroptera. A slight increase in March was offset by decreased trichopteran and dipteran abundance (*Agapetus* sp., *Hydropsyche* sp., *Cricotopus* sp., and *Eukiefferiella* sp.). Though *Atherix variegata* and *Simulium arcticum* decreased in April, other major genera showed a considerable increase accounting for the peak seen on this date. In May, with the increased runoff, there was a drastic decline in abundance of the major genera. In June there was a slight recovery in *Glossosoma* sp. and *Simulium arcticum*, but the rest of the taxa remained fairly low in density.

This pattern of seasonal abundance is common in streams. The fall increase is prevalent in streams of this type as a result of the hatching of eggs and subsequent growth of the larvae of summer emergent species (Hynes 1970). The sharp decline in the early winter samples may result from a variety of factors including initial ice formation, downward migration of the macrobenthos into the hyporheic and the emergence of fall species (Hynes 1970). The increased numbers in spring may result from the hatching of overwintering eggs and the renewed growth of the existing organisms (and thus increased sampling efficiency). The peak was reached before the spring runoff. Runoff from snowmelt in the upper basin could account for much of the decreased abundance at the sites in late spring. The emergence of some organisms could also account for the drop in density on these dates. The standing crop of the stream macroinvertebrates varies temporally according to the life history patterns of the dominant organisms, and this is seen in Trout Creek (Table 13 and discussion above).

Statistical analysis of variance was run on the raw numbers with $\log_{10}$ transformation for the dates to determine the degree of strength in the trend seen above. The results of the analysis (Table 14) show significant difference between the dates (at 0.01 level), which supports the trend seen in Figure 4.

B. YEAR TWO: JULY 1976 TO APRIL 1977

1. Macrobenthos

During the second year of study, 69 taxa were identified at the two sites (C2 and C4) on Trout Creek (Appendix B). Only 17 were considered numerically abundant. Many of these were also the abundant species found during the first year of study.

Mean standing crop at C2 was 3991 organisms and 12.5 g per m^2 compared with 3522 organisms and 15.3 g per m^2 during the same period the preceding year. For site C4, the values were 3111 organisms and 11.7 g per m^2 (1976-1977), and 2935 organisms and 12.0 g per m^2 (1975-1976).

Mean density over the 10 months showed a general decrease from C2 to C4 (Figure 7) as in the first year (Figure 2), although at higher density values. Biomass also decreased from site C2 to site C4 (Table 15). As in the first year, the general trend shows a drop in standing crop at C4, which is below the older mine spoils and drainage from the current mining activity.

TABLE 14. ANALYSIS OF VARIANCE TABLE FOR THE SAMPLING DATES (JULY 1975 TO JUNE 1976), TROUT CREEK, COLORADO

Source of variation	Sum of squares	Degrees of freedom[a]	Mean square	F-ratio
Between dates	1.52	11	0.16	4.0[b]
Within dates	2.51	65	0.04	
Total	4.33	76		

[a]Based upon unequal sample size.

[b]Significant at the 0.01 level.

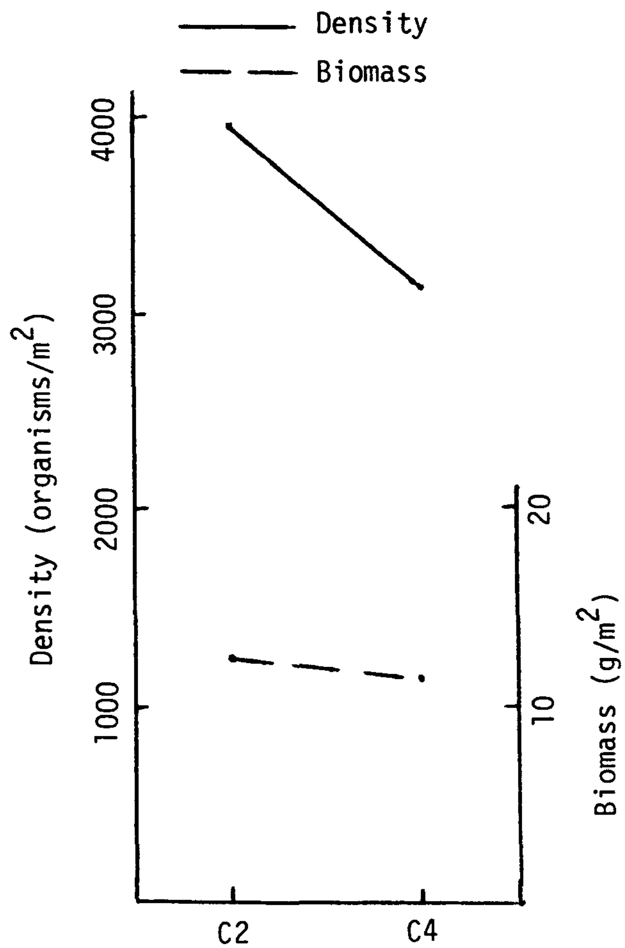

Figure 7. Mean standing crop of benthic macroinvertebrates in Trout Creek, Colorado, July 1976 to April 1977.

TABLE 15. MEAN BIOMASS VALUES[a] FOR THE MAJOR TAXA FOUND AT SITES C-2 AND C-4 (JULY 1976 TO APRIL 1977), ON TROUT CREEK, COLORADO

Taxa	C2	C4
Trichoptera	4.8	6.9
Diptera	2.4	1.1
Ephemeroptera	1.2	1.2
Plecoptera	2.2	1.4
Coleoptera	0.9	0.6
Hydracarina	0.1	+[b]
Mollusca	0.1	0.7
Oligochaeta	+	+
Hirudinea	--	+
Nematoda	+	--
Total	12.5	11.7

[a] g/m^2 wet weight based upon volumetric conversion.

[b] + = present but less than 0.1 g/m^2.

The aquatic insects comprised over 90% of the standing crop at both sites as in the first year (Table 16). The decrease in standing crop at C4 was due primarily to a reduced abundance of Diptera, Plecoptera, and Hydracarina (especially *Pericoma* sp., *Orthocladius* sp., *Prostoia besametsa*, and *Protzia* sp.). Trichoptera increased in relative abundance (notably *Hydropsyche* sp. and *Glossosoma* sp.), dominating both the density and biomass at site C4.

Statistical analysis of variance was run on the raw numbers of organisms per sample with $\log_{10}$ transformation for the 22 months of data to determine if there was a difference between sites C2 and C4. The results (Table 17) showed no difference between the sites. This suggests that differences are due to more subtle changes in relative abundance of a few taxa rather than gross changes in the entire fauna.

2. Macrobenthic composition

Aquatic insects comprised roughly 80% of the total number of taxa found during the second year of study, with the Trichoptera and Diptera accounting for 58% of the insect species (Table 18). Trichoptera dominated the fauna with 56% of the density and 48% of the biomass (Table 16). Diptera comprised 13% of the density and 14% of the biomass while Ephemeroptera made up 8% of the density and 10% of the biomass. As in year one, the stoneflies and beetles mirrored each other with the Plecoptera accounting for 4% of the density and 15% of the biomass, while Coleoptera accounted for 15% of the density and 6% of the biomass.

The number of species at the two sites during the second year of study (Table 18) was similar, although slightly lower than the number of species found in the first year (Table 8). The lower number of species at site C4 was due mainly to fewer species of aquatic insects.

Trichoptera species were quite similar at both sites with only a few rare specimens found at just one site (e.g., *Oligophlebodes* sp. and *Helicopsyche* sp. at C2 and C4, respectively). In the data for year one (Appendix A) these two sites appear to be the boundary zone between those species found only at the upper sites (e.g., *Oligophlebodes* sp.) and those found mainly at the lower sites (e.g., *Cheumatopsyche* sp.). The sites had similar faunal components with the differences being primarily in abundance. *Hydropsyche* sp. and *Glossosoma* sp. exhibited greater density at C4, while *Lepidostoma* sp. decreased greatly at this site. There were relatively fewer *Hydroptila* sp. at site C2 compared to the previous year.

Dipteran species were also similar at the two sites; however, large decreases in abundance of *Pericoma* sp. and *Orthocladius* sp. at the lower site accounted for the lower density. The main difference from year one in this group is the absence of large numbers of *Simulium arcticum* at C4 during the second year.

Ephemeroptera were very similar at both sites for both years. The greater abundances of *Rhithrogena* sp. at C2 and *Ephemerella inermis* at C4 were the only major differences between the two sites for this group.

TABLE 16. MEAN PERCENTAGE COMPOSITION OF THE FIVE MAJOR INVERTEBRATE GROUPS BY DENSITY AND BIOMASS FOR SITES C2 AND C4 (JULY 1976 TO APRIL 1977), ON TROUT CREEK, COLORADO

Taxa	C2	C4	Both sites
	Density		
Trichoptera	48	66	56
Diptera	19	5	13
Ephemeroptera	8	8	8
Plecoptera	5	3	4
Coleoptera	16	14	15
Total	96	96	96
	Biomass		
Trichoptera	38	59	48
Diptera	19	9	14
Ephemeroptera	10	10	10
Plecoptera	18	12	15
Coleoptera	7	5	6
Total	92	95	93

TABLE 17. ANALYSIS OF VARIANCE FOR THE SITES C2 AND C4 (JULY 1975 TO APRIL 1977), ON TROUT CREEK, COLORADO

Source of variation	Sum of squares	Degrees of freedom[a]	Mean square	F-ratio
Between sites	0.07	1	0.07	1.2[b]
Within dates	2.48	41	0.06	
Total	2.55	42		

[a]Based upon unequal sample size.

[b]Not significant.

TABLE 18. NUMBER OF SPECIES IN EACH MAJOR TAXON FOR SITES C2 AND C4 (JULY 1976 TO APRIL 1977), ON TROUT CREEK, COLORADO

Taxa	C2	C4
Trichoptera	13	12
Diptera	16	15
Ephemeroptera	8	7
Plecoptera	9	7
Coleoptera	4	5
Hydracarina	4	4
Mollusca	3	5
Oligochaeta	2	2
Hirudinea	0	1
Nematoda	1	0
Total	60	58

The greater number of species of Plecoptera at site C2 was again due to the presence of the winter stoneflies (*Leuctra glabra* and *Paraleuctra sara*) not found at C4. Generally, the other stoneflies were found at both sites with *Prostoia besametsa* providing the higher density at C2.

The Coleoptera were dominated by two species, *Optioservus seriatus* and *Zaitzevia parvula*. *Z. parvula* showed decreased abundance at site C4, whereas *O. seriatus* had similar density values at both sites in both years.

The number of species of Hydracarina was the same at both sites, although all of the species had greater abundance at site C2 (as in year one).

More species and numbers of Mollusca occurred at C4, although the reasons for this are unclear.

As in the first year, only two species of Oligochaeta were identified at the two sites, with neither of them being very abundant. One specimen of the leech, *Helobdella stagnalis*, was collected at the lower site.

Nematoda occurred infrequently during the second year and could not be properly identified.

3. Diversity

Diversity values (Shannon-Weaver index and equitability) were similar at the two sites for the second year (Table 19). Mean number of species was lower at site C4 due mainly to reduced diversity of dipterans. The diversity index values fall essentially in the "normal" range of Wilhm (1970).

4. Seasonal trends

The seasonal density values, both sites combined, ranged from 838 organisms/m^2 in October 1976 to 5123 organisms/m^2 in July 1976. Density peaked in September and April (Figure 8). Biomass values ranged from 2.7 g/m^2 in October to 22.0 g/m^2 in July 1976 (Table 20), closely following the pattern of density values. Diversity (as mean number of species) showed greater periodicity than in the first year and closely followed the standing crop.

The sites followed somewhat the pattern of the first year with site C2 again peaking in the spring. This was mainly due in both years to the large number of Chironomidae found associated with the *Hydrurus foetidus* (Chrysophyta), which coats the substratum at this site in spring.

As in year one, trends can be explained by changes in the five major faunal groups (Table 21). The slight decrease in August was due primarily to decreases in Trichoptera and Coleoptera abundance, especially *Brachycentrus americanus*, *Glossosoma* sp., and *Zaitzevia parvula* (Table 22). The subsequent rise of Diptera and Coleoptera in September more than compensated for decreases in the Trichoptera. The large increases in *Orthocladius* sp., *Cricotopus* sp., *Rheotanytarsus* sp. and *Optioservus seriatus* overshadowed

TABLE 19. MEAN NUMBER OF TAXA AND THE RANGE OF VALUES FOR THE SHANNON-WEAVER INDEX AND EQUITABILITY FOR THE SITES ON TROUT CREEK, COLORADO, JULY 1976 TO APRIL 1977

Number, index, equitability	C2	C4
Mean number of species	35	30
Shannon-Weaver index	2.6-4.0	2.4-3.8
Equitability	0.26-0.59	0.29-0.70

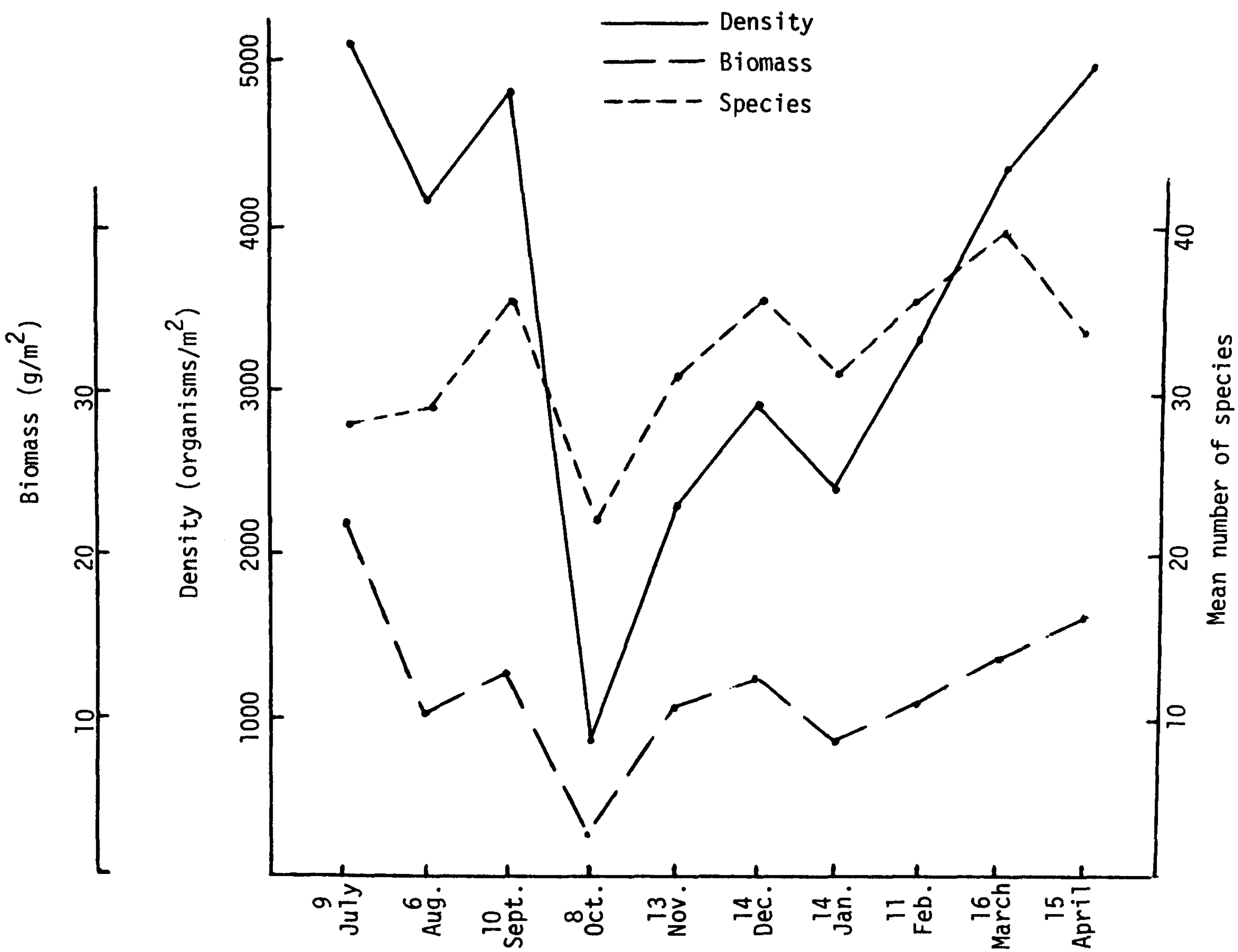

Figure 8. Seasonal trends in macroinvertebrate diversity, density, and biomass at Trout Creek, Colorado, July 1976 to April 1977, plotted as means of sites C2 and C4 combined.

TABLE 20. SEASONAL VALUES IN MACROINVERTEBRATE STANDING CROP AND MEAN NUMBER OF SPECIES AT TROUT CREEK, COLORADO (JULY 1976 TO APRIL 1977), MEANS OF SITES C2 AND C4 COMBINED

Density, biomass, species	9 July	6 Aug.	10 Sept.	8 Oct.	13 Nov.	14 Dec.	14 Jan.	11 Feb.	16 March	15 April
Density (organisms/m^2)	5123	4180	4858	838	2331	2987	2424	3380	4392	4995
Biomass (g/m^2)	22.0	10.2	13.0	2.7	10.8	12.7	8.6	11.0	13.8	16.0
Mean species	28	29	36	22	31	36	31	36	40	34

TABLE 21. MEAN DENSITY (ORGANISMS/M^2) OF THE FIVE MAJOR INVERTEBRATE GROUPS AT SITES C2 AND C4 FOR JULY 1976 TO APRIL 1977, TROUT CREEK, COLORADO

Taxa	9 July	6 Aug.	10 Sept.	8 Oct.	13 Nov.	14 Dec.	14 Jan.	11 Feb.	16 March	15 April
Trichoptera	4090	3219	2994	171	1366	1247	1311	1798	2093	1633
Diptera	157	137	579	60	174	540	177	295	560	1855
Ephemeroptera	197	228	335	6	217	260	400	358	524	514
Plecoptera	42	43	97	9	136	179	62	191	368	379
Coleoptera	626	506	725	465	310	571	393	525	668	552
Total	5123	4180	4858	838	2331	2987	2424	3380	4392	4995

TABLE 22. SEASONAL TRENDS FOR THE MAJOR GENERA FOR SITES C2 AND C4 (JULY 1975 TO APRIL 1977) ON TROUT CREEK, COLORADO (ORGANISMS/M^2)

Taxa	9 July	6 Aug.	10 Sept.	8 Oct.	13 Nov.	14 Dec.	14 Jan.	11 Feb.	16 March	15 April
Brachycentrus americanus	1580	363	198	4	82	64	111	155	150	182
Lepidostoma sp.	445	1256	889	86	355	400	180	510	564	368
Agapetus sp.	1688	1295	1582	33	759	400	251	295	330	194
Glossosoma sp.	315	13	34	8	21	221	554	680	861	777
Hydropsyche sp.	48	95	262	16	129	152	166	149	178	101
Pericoma sp.	1	--	32	9	111	118	75	142	150	94
Orthocladius sp.	14	27	103	5	5	228	10	--	154	1479
Cricotopus sp.	22	79	233	26	20	70	17	28	22	19
Rheotanytarsus sp.	47	14	132	--	--	3	28	13	21	35
Baetis sp.	168	104	116	1	51	24	35	45	157	141
Rhithrogena sp.	1	14	120	2	72	75	225	151	199	200
Ephemerella inermis	--	3	--	--	29	59	80	88	102	77
Alloperla sp.	27	28	27	15	108	144	37	116	155	88
Prostoia besametsa	--	--	--	--	7	4	1	53	175	272
Optioservus seriatus	187	186	360	214	198	309	285	305	392	323
Zaitzevia parvula	435	319	364	249	112	262	104	219	274	226
Protzia sp.	3	10	57	42	53	40	8	110	45	19
Physa sp.	--	1	36	2	38	110	62	75	105	27

large decreases in *Brachycentrus americanus* and *Lepidostoma* sp. The tremendous decrease in standing crop in October occurred in all major groups, with the smallest decrease occurring in Coleoptera. The increase through December was present in all major groups with the largest occurring in the Trichoptera in November and the Diptera in December. The Coleoptera decreased in November, but recovered in December. Ephemeroptera (*Rhithrogena* sp.) and Trichoptera (*Brachycentrus americanus*, *Glossosoma* sp.) increased in abundance in January, although the other groups exhibited decreased numbers.

Statistical analysis of variance was run on the raw data with $\log_{10}$ transformation to determine the strength of the trend seen above. The results (Table 23) showed significant difference between the dates (at 0.05 level).

5. Epilithic Algae

Qualitative samples of epilithon scraped from the upper surfaces of rubble-sized rocks showed a diverse algal flora. Appendix C lists the epilithic algae collected from sites C2 and C4. Diatoms (Bacillariophyta) comprised approximately 80% of the species at both locations. Chlorophytes and cyanophytes were also represented. A single species of Chrysophyta (*Hydrurus foetidus*) occurred at both sites and the chantransia stage of a Rhodophyta was identified from site C2.

TABLE 23. ANALYSIS OF VARIANCE FOR THE DATES (JULY 1976 TO APRIL 1977) OF TROUT CREEK, COLORADO

Source of variation	Sum of squares	Degrees of freedom	Mean square	F-ratio
Between dates	1.23	9	0.14	4.6[a]
Within dates	0.30	10	0.03	
Total	1.53	19		

[a]Significant at 0.05 level.

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APPENDIX A

Macrobenthos species list and mean density for the sampling sites on Trout Creek, Colorado, July 1975-June 1976

Taxa	Density (organisms/m^2)						
	C0	C1	C2	C4	C6	C8	C9
TRICHOPTERA	1388	560	950	1505	2095	2202	2314
Brachycentrus americanus	136	338	457	240	373	511	91
Lepidostoma sp.	263	38	256	30	27	52	14
Agapetus sp.	450	179	301	846	958	1034	38
Glossosoma sp.	29	2	9	78	318	87	16
Rhyacophila angelita	9	4	7	7	15	13	1
Arctopsyche sp.	21	22	13	37	15	13	47
Hydropsyche sp.	42	30	45	322	284	388	541
Cheumatopsyche sp.	4	1	--	+[a/]	1	30	1376
Oligophlebodes sp.	343	4	1	+	+	--	--
Neothremma sp.	11	+	+	--	--	21	--
Hesperophylax sp.	+	+	+	2	5	15	--
Limnephilus sp.	--	--	--	--	--	+	--
Pycnopsyche sp.	--	--	--	--	--	+	--
Wormaldia sp.	+	--	+	6	3	9	--
Helicopsyche sp.	--	--	--	+	+	2	117
Hydroptila sp.	31	2	128	5	8	13	61
Leucotrichia sp.	--	--	--	--	--	--	+
Psychomyia sp.	--	--	--	--	--	+	1
DIPTERA	366	598	728	333	308	611	2304
Atherix variegata	37	91	32	18	12	9	271
Simulium arcticum	51	81	44	167	16	9	513
Hexatoma sp.	10	8	13	15	23	24	24
Antocha sp.	17	+	5	+	11	22	42
Tipula sp.	--	--	+	--	--	--	--
Palpomyia sp.	+	--	--	+	--	2	+
Deuterophlebia sp.	+	+	+	--	--	--	--
Euparyphus sp.	--	--	--	+	--	+	+

Appendix A. Cont.

Taxa	Density (organisms/m^2)						
	C0	C1	C2	C4	C6	C8	C9
DIPTERA (Cont.)							
Chelifera sp.	1	+	2	3	9	4	8
Wiedemannia sp.	--	--	--	--	+	+	--
Pericoma sp.	43	26	64	8	4	3	+
Eukiefferiella sp.	33	23	110	28	32	116	123
Rheotanytarsus sp.	12	--	1	14	2	--	--
Orthocladius sp.	67	102	110	48	96	258	718
Cricotopus sp.	48	131	286	18	63	44	121
Pentaneura sp.	1	+	+	+	2	2	--
Microtendipes sp.	--	--	+	--	16	11	154
Cardiocladius sp.	2	38	4	--	--	--	--
Brillia sp.	--	--	2	--	--	--	--
Heterotrissocladius sp.	+	--	--	--	--	--	--
Pseudodiamesa sp.	6	+	30	--	--	--	--
Diamesa sp.	--	81	10	3	16	64	--
Pseudochironomus sp.	--	--	--	--	--	--	35
EPHEMEROPTERA	388	425	706	451	761	646	1142
Baetis sp.	133	136	313	114	229	257	412
Epeorus longimanus	14	43	26	8	3	2	+
Rhithrogena sp.	123	258	325	325	239	124	55
Ephemerella grandis	81	29	27	49	88	60	9
E. inermis	4	2	3	11	77	88	177
E. micheneri	3	2	7	26	105	107	271
E. margarita	+	+	+	+	3	+	--
E. hecuba	--	+	+	+	+	4	--
Tricorythodes sp.	+	--	--	--	+	+	37
Paraleptophlebia heteronea	2	2	6	4	3	15	9
Ameletus sparsatus	+	+	2	--	+	+	--
Ameletus oregonensis	--	--	--	+	--	--	--
PLECOPTERA	154	136	305	83	149	154	133
Pteronarcella badia	82	39	29	13	17	15	10
Pteronarcys californica	+	+	--	+	2	4	+
Claassenia sabulosa	9	5	12	10	9	4	1
Acroneuria sp.	+	--	--	--	--	--	--
Alloperla sp.	23	49	63	46	106	103	89

Appendix A. Cont.

Taxa	Density (organisms/m^2)						
	C0	C1	C2	C4	C6	C8	C9
PLECOPTERA (Cont.)							
Isogenus sp.	2	+	+	4	4	7	12
Arcynopteryx parallela	3	2	3	3	6	10	6
Prostoia besametsa	--	40	195	6	6	11	16
Zapada sp.	--	+	+	+	+	--	--
Paraleuctra sara	--	3	+	--	+	--	--
Leuctra glabra	--	+	+	--	--	--	--
COLEOPTERA	527	390	533	238	430	431	987
Optioservus seriatus	264	120	175	131	341	333	890
Zaitzevia parvula	246	110	245	112	98	93	97
Narpus sp.	3	+	2	+	+	+	--
Helichus sp.	1	+	1	+	1	1	--
Deronectes sp.	+	--	--	+	+	1	--
Oreodytes sp.	--	+	+	+	+	+	--
Agabinus sp.	--	--	--	+	--	--	--
Brychius sp.	--	--	--	+	--	--	--
Hydaticus sp.	--	--	--	+	--	--	--
HEMIPTERA							
Corixidae	--	--	--	--	--	+	--
Notonecta sp.	--	+	--	+	+	--	+
ODONATA							
Ophiogomphus sp.	--	--	--	--	--	+	--
HYDRACARINA	48	26	39	9	10	15	12
Protzia sp.	27	11	18	2	2	2	--
Mideopsis sp.	7	6	9	2	3	5	12
Lebertia sp.	8	3	5	+	2	4	+
Limnochares sp.	3	3	3	+	+	--	1
MOLLUSCA	3	1	+	9	54	37	25
Physa sp.	+	+	+	9	48	32	10
Lymnaea sp.	+	+	--	+	3	+	+
Ferrissia sp.	--	--	--	+	3	4	14
Pisidium sp.	2	+	+	--	1	1	+

Appendix A. Cont.

Taxa	Density (organisms/m^2)						
	C0	C1	C2	C4	C6	C8	C9
OLIGOCHAETA	+	2	1	1	+	5	106
Eiseniella tetraedra	+	2	1	1	+	5	7
Limnodrilus sp.	--	--	--	--	--	--	99
NEMATODA	2	2	1	+	+	1	8
TURBELLARIA							
Dugesia sp.	+	--	--	--	--	--	--
Total	2930	2178	3146	2730	3800	4124	7089

a/ + = present but less than 1.0/m^2.

APPENDIX B

Macrobentho species list and mean density values (organisms/m^2) for sites C2 and C4, July 1976-April 1977, on Trout Creek, Colorado

Taxa	Density (organisms/m^2) C2	C4
TRICHOPTERA	1918	2066
Brachycentrus americanus	225	353
Lepidostoma sp.	882	129
Agapetus sp.	555	811
Glossosoma sp.	171	526
Rhyacophila angelita	3	2
Hydropsyche sp.	41	227
Arctopsyche sp.	4	5
Cheumatopsyche sp.	--	+[a/]
Helicopsyche sp.	--	6
Hydroptila sp.	20	2
Neotrichia sp.	16	1
Leucotrichia sp.	+	--
Wormaldia sp.	1	2
Oligophlebodes sp.	1	--
Limnephilus sp.	+	--
DIPTERA	754	171
Atherix variegata	30	15
Simulium arcticum	7	2
Hexatoma sp.	28	19
Pericoma sp.	139	8
Chelifera sp.	8	5
Deuterophlebia sp.	+	--
Antocha sp.	10	2
Hesperoconopa sp.	1	--
Palpomyia sp.	6	+
Maruina lanceolata	--	1

Appendix B. Cont.

Taxa	Density (organism/m^2)	
	C2	C4
DIPTERA (Cont.)		
Orthocladius sp.	375	30
Rheotanytarsus sp.	34	20
Cricotopus sp.	79	28
Microtendipes sp.	3	10
Diamesa sp.	14	3
Eukiefferiella sp.	6	1
Psectrocladius sp.	26	7
EPHEMEROPTERA	343	265
Baetis sp.	93	75
Rhithrogena sp.	158	53
Epeorus longimanus	13	2
Ephemerella grandis	37	44
E. inermis	14	74
E. margarita	3	4
Ameletus sparsatus	5	--
Paraleptophlebia heteronea	15	13
PLECOPTERA	219	84
Alloperla sp.	89	68
Prostoia besametsa	101	2
Claassenia sabulosa	20	7
Acroneuria sp.	+	--
Pteronarcella badia	6	2
Pteronarcys californica	+	1
Arcynopteryx parallela	11	3
Paraleuctra sara	1	--
Leuctra glabra	+	--
COLEOPTERA	637	432
Optioservus seriatus	289	263
Zaitzevia parvula	345	168
Narpus sp.	1	--
Helichus sp.	2	+
Laccophilus sp.	--	+
Oreodytes sp.	--	+

Appendix B. Cont.

Taxa	Density (organisms/m^2)	
	C2	C4
HYDRACARINA	106	14
Protzia sp.	71	6
Lebertia sp.	14	1
Mideopsis sp.	14	4
Limnochares sp.	21	3
MOLLUSCA	3	97
Physa sp.	1	90
Lymnaea sp.	2	6
Pisidium sp.	+	+
Gyraulus sp.	--	+
Ferrissia sp.	--	+
OLIGOCHAETA	4	+
Eiseniella tetraedra	3	+
Limnodrilus sp.	+	+
HIRUDINEA		
Helobdella stagnalis	--	+
NEMATODA	+	--
Total	3991	3111

APPENDIX C

Species of epilithic algae collected at sites C2 and C4 on Trout Creek, Colorado[a/]

Taxa	C2	C4
BACILLARIOPHYTA		
Achnanthes lanceolata	X	X
A. minutissima	X	X
Asterionella formosa	X	X
Cocconeis pediculus	X	X
C. placentula		X
Cyclotella sp.	X	X
Cymbella minuta	X	X
C. prostrata	X	
C. tumida	X	
Diatoma hiemale	X	X
D. vulgare	X	X
Epithemia sorex	X	X
Eunotia pectinalis		X
Fragilaria construens	X	X
F. vaucheriae		X
Frustulia rhomboides	X	
Gomphonema olivaceum	X	X
G. subclavatum	X	X
Gyrosigma obtusatum	X	
Hannea arcus	X	X
Hantzschia amphioxys	X	
Melosira varians	X	
Meridion circulare	X	X
Navicula sp.	X	X
N. cryptocephala	X	X
N. exigua	X	
N. gastrum	X	
N. pupula	X	
N. radiosa	X	X
N. rhyncocephala	X	X

Appendix C. Cont.

Taxa	C2	C4
BACTILLARIOPHYTA (Cont.)		
N. tripunctata	X	
N. viridula	X	X
Nitzschia sp.	X	X
N. acicularis	X	X
N. apiculata	X	
N. dissipata	X	X
N. hungarica	X	
N. linearis	X	X
N. palea	X	X
N. sigmoidea	X	
Pinnularia mesolepta	X	
Rhoicosphenia curvata	X	X
Rhopalodia gibba	X	
Surirella augustata	X	X
S. ovalis	X	X
Synedra ulna	X	X
Synedra ulna var. *impressa*	X	
CHLOROPHYTA		
Chlamydomonas sp.		X
Closterium sp.	X	
Ulothrix sp.	X	
CHRYSOPHYTA		
Hydrurus foetidus	X	X
CYANOPHYTA		
Anabaena sp.	X	X
Dactylococcopsis raphidioides	X	
Lyngbya sp.	X	X
Nostoc palmeloides	X	X
Oscillatoria sp.	X	X
Phormidium sp.	X	X
Tolypothrix sp.	X	X

Appendix C. Cont.

Taxa	C2	C4
RHODOPHYTA		
Nemalion "chantransia"	X	
Total number of species	55	39

[a]/From qualitative samples scraped from upper surfaces of rubble-sized rocks on October and November 1976, April and May 1977 at C2, and January, February, and March 1977 at C4.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/3-78-095	2.
	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE ENVIRONMENTAL EFFECTS OF WESTERN COAL SURFACE MINING PART II - THE AQUATIC MACROINVERTEBRATES OF TROUT CREEK, COLORADO	5. REPORT DATE October 1978 issuing date
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15. SUPPLEMENTARY NOTES

16. ABSTRACT

A study was conducted on Trout Creek in northwestern Colorado to assess effects of coal mine drainage on stream macroinvertebrates. Density and biomass exhibited a general increase in the downstream direction throughout the study area and showed marked seasonal variation. Aquatic insects comprised over 90% of the fauna with caddisflies (Trichoptera) predominating. Diversity did not vary significantly throughout the study area. None of the parameters measured showed any definite indication of stressed conditions in the macroinvertebrate community during the study period. Water quality was diminished primarily during spring runoff and the invertebrates seemed able to withstand this short period of water quality degradation. The buffer zone present between the mine area and Trout Creek may decrease the effects of mine drainage and should remain to insure the maintenance of a stable macroinvertebrate community in Trout Creek.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Coal Coal mining Invertebrates Water pollution Biological survey Benthos	Effects of mining Environmental effects Environmental biology	06/F 13/B

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